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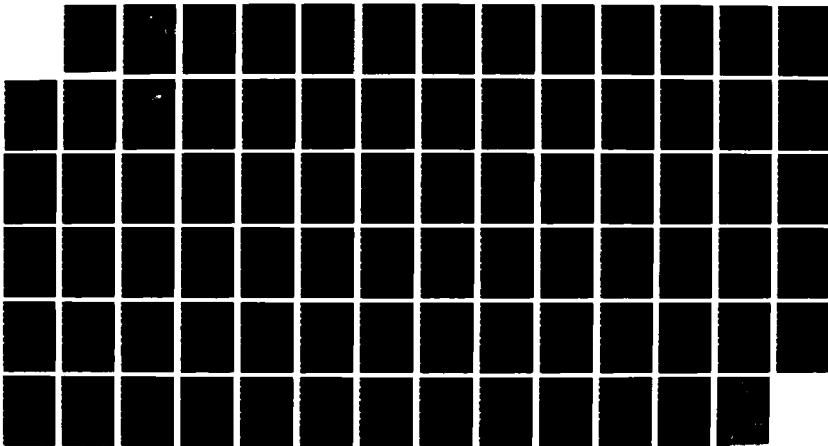
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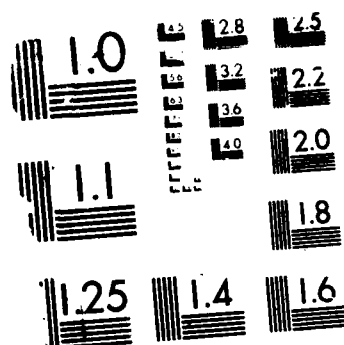
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WEAPON SYSTEM PROGRAMS

THESIS

Cynthia L.A. Norman
Captain, USAF

AFIT/GSM/LSY/87S-24

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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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AFIT/GSM/LSY/87S-24

SOFTWARE MANAGEMENT FOR
WEAPON SYSTEM PROGRAMS

THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Systems Management

Cynthia L.A. Norman, B.S.

Captain, USAF

September 1987

Approved for public release; distribution unlimited

Preface

This research was prompted by concern expressed by numerous colleagues and friends about the lack of software expertise in weapon system program offices. The purpose of this research was to find out exactly what type of software support existed in the program offices, and from that information, develop recommendations for possible improvement of the software support. The information from this study may be useful to those who determine the education and training requirements of software personnel in the program offices.

While performing this research and writing this thesis, I have had the support of numerous people. I have many thanks for my thesis advisor, Capt Roger Davis, for his assistance, guidance and patience, and for allowing me to pursue the research to my own design. I am also greatly indebted to the five system program offices (SPOs) in the Aeronautical Systems Division for their cooperation and information. Without their cooperation, I would not have been able to complete this research. Finally, I wish to express my love and thanks to my husband Jim for his understanding and support throughout this endeavor.

Cynthia L.A. Norman

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Abstract

Research and development of new weapon systems can be very expensive. In addition, the maintenance of these new systems can be expensive, adding to the overall life cycle cost of the systems. Proper design of the new systems can lessen the maintenance costs. However, more and more, weapon systems are not just a product of hardware engineering. Computer systems and software help to run the systems more efficiently and make it easier for humans to control the sophisticated hardware.

The Air Force Systems Command is currently the main procurer of new weapons systems for the Air Force. In particular, the Aeronautical Systems Division (ASD) buys aircraft and aircraft systems for the Air Force. Currently, ASD has a "pool" of engineers for program offices to draw upon whenever hardware technical expertise is needed, but the pool of software experts is very small. Do the majority of the program offices need such a pool of software experts, and if they do, what type of educational and work experience should these people have?

To answer this question, the views of people who are in the program offices were collected. Program managers and software personnel were asked to give their views on education, training, and work experience.

The overwhelming response is that the program offices do need software experts, and that even though they have someone in the office who is the designated software person, the program offices still do not have enough support in the management of software. Additionally, the recommended educational background is in a computer engineering

discipline. Computer engineering combines education in both the hardware and the software of a computer. This education should be enhanced with training in systems acquisition and computer resources acquisition management. If possible, many of the program offices would like their personnel to come to the program with prior program office experience.

SOFTWARE MANAGEMENT FOR WEAPON SYSTEM PROGRAMS

I. Introduction

Research and development of new weapon systems can be very expensive. In addition, the maintenance of these new systems can be expensive, adding to the overall life cycle cost of the systems. Proper overall design of Air Force weapon systems helps to hold down maintenance costs later in the life of those systems. In order to ensure proper design, the Air Force uses a staff of engineers to evaluate and monitor the design of its research and development projects. However, more and more, weapon systems are not just a product of hardware engineering. Software is increasingly playing a part in weapon systems. According to James Canan, senior editor of Air Force Magazine, ten years ago, the B-1A bomber used 500,000 lines of code, less than half of the 1,200,000 lines of code in the current B-1B (10:46). Computer systems and software help to run the systems more efficiently and make it easier for humans to control the sophisticated hardware. Good software engineering and management should also help bring down the system maintenance costs, but is the Air Force doing enough to ensure that good design is used in the development of weapon system software?

Specific Problem

The Air Force Systems Command is currently the main procurer of new weapon systems for the Air Force. In particular, the Aeronautical Systems Division (ASD) buys aircraft and aircraft systems for the Air

Force. Currently, ASD has a "pool" of engineers for program offices to draw upon whenever hardware technical expertise is needed. These engineers include electrical engineers, mechanical engineers, chemical engineers, aeronautical engineers, and others who help with the structural design of the aircraft. In addition, there are some software and computer systems experts. However, there are not enough available software personnel for all of the program offices to use. To make up for the lack of personnel, ASD's Deputy for Engineering educates its hardware engineers in computer systems and software. Using a limited amount of training, these engineers act as technical representatives for computer systems and software to the program offices (5). With the continually increasing number of software systems used on aircraft, is there a need for software personnel in the program offices, and if there is, what type of educational background and work experience should these people have?

Justification

In 1980, the annual cost of software was approximately 40 billion dollars (7:17). In 1976, Dr Barry Boehm stated that compared to the cost of hardware, software costs were going to grow as depicted in Figure 1 (7:17-18). If Dr Boehm's prediction was even partially true, software costs have risen to a level that should cause concern.

In a joint memorandum, dated 15 October 1985, the Air Force Chief of Staff and the Secretary of the Air Force stated that the Air Force spent about \$3 billion each year on mission-critical software (22). This memorandum was written as a result of an Air Force study of software

MCCR include automatic data processing equipment and services that are generally involved with:

- intelligence activities;
- cryptologic activities related to national security;
- command and control of military forces;
- equipment that is an integral part of a weapon or weapon system, or;
- is critical to direct fulfillment of military or intelligence missions (23:9).

MCCR does not include automatic data processing equipment and services used for "routine administrative and business applications such as payroll, finance, logistics, or personnel management" (20:6).

Manpower constraints will not be covered. Instead, the need for software personnel in program offices and their qualifications is the focus of this research. Whether or not the Air Force has the required number of personnel is beyond the scope this research.

In addition, the programs that will be studied will be limited to programs at the Aeronautical Systems Division at Wright-Patterson Air Force Base, Ohio. Due to the diversity of aircraft systems handled at ASD, hardware concerns will not be addressed.

Research Questions

There are six research questions associated with this thesis:

1. What proportion of the overall program costs include software costs?
2. How many of the program offices have some kind of software expertise resident in the office?
3. If the office does not have a software expert in the office, who does the job of ensuring good software design?

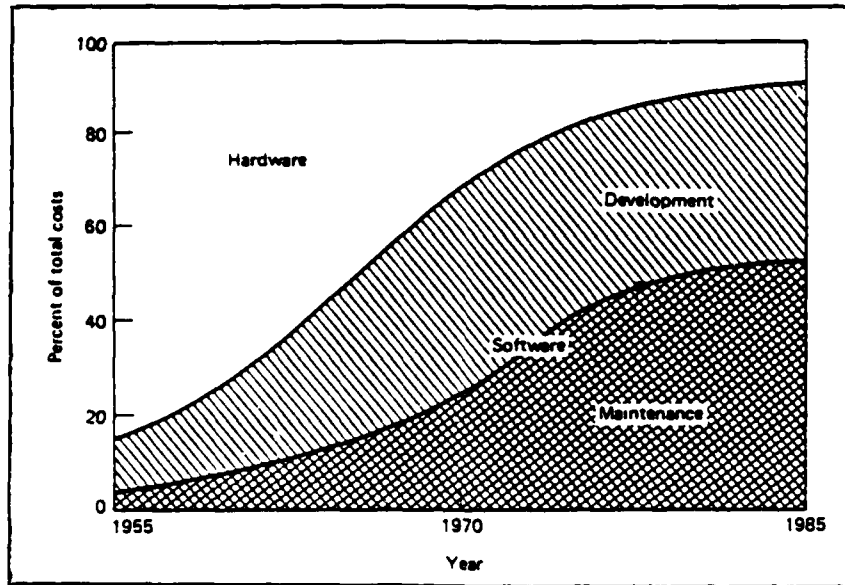


Figure 1. Hardware/Software Cost Trends

management called "Project Boldstroke." According to General Charles Gabriel and Secretary Vern Orr,

The study confirmed that our software management expertise has not kept pace with the rapid spread and technological advances in computer-based weapon and information systems....Our newest weapons and information systems--the B-1, Peacekeeper, SACDIN, and the Phase IV Standard Base Supply System--depend upon sophisticated software. In a very real sense, our ability to deliver and support this software in a timely and cost-effective manner provides the Air Force its most significant technological edge over our potential adversaries. (22)

This research takes the next logical step in that its purpose is to find out what type of software support is already in place in the program offices.

Scope of the Research

Because of the two classifications of software, and the different regulations governing the acquisition of each classification, this research will be limited to Mission Critical Computer Resources (MCCR).

4. What other tasks do these people have?
5. What type of educational background and work experience do the software personnel have?
6. What other education and experience might be needed?

Summary

With the amount of software needed on weapon systems now, it is important for the Air Force to ensure that the contractor-developed software is properly managed early in the program. Having well-qualified personnel with the appropriate education and experience may help to keep the costs of software down. The purpose of this research is to find out if those people are needed, what support already exists and who those people are, and what type of education and experience they should have.

II. Software Management

This chapter contains information resulting from a literature review. It is presented to provide background information concerning the need for software management in Department of Defense (DoD) weapon system programs. First, the obstacles to effective software management are presented. Then, there is a discussion of how the DoD and the Air Force is trying to overcome these obstacles. Finally, other topics that are important for software management are briefly covered.

Terms Defined

Before going into the discussion of software management, some terms which are basic to the subject need to be defined.

Hardware is defined in Webster's (26:637) as "heavy military equipment or its parts," and as "the mechanical, magnetic, and electronic design, structure, and devices of a computer." In this paper, hardware will include computers and the weapon systems (such as aircraft) that carry devices that use software. These devices can include equipment such as aircraft avionics and missile guidance systems.

Software includes the programs, data, and routines that are used by a computer to perform various functions (26:1353). The programs, data, and routines provide instructions to the computer which tell the computer what steps should be taken when encountering certain prescribed conditions. The software may be stored on magnetic disk, tape, or in the main memory of the computer.

Software Engineering is a discipline concerned with "the development and utilization of methodologies and techniques for designing, imple-

menting, and maintaining software systems" (21:11). In other words, software engineering involves the use of some kind of pre-defined plan and method for designing and developing a software system. The method may be a new one just developed, or one of the many existing software development methodologies.

Software Management can be broken down into its two component parts. Software was defined above, and management can be defined as "the act, art, or manner of managing, or handling, controlling, directing, etc." (26:859). From these two definitions, software management can be defined as the act of controlling programs, data, and routines used by a computer, so that they are made useful to man.

Obstacles to Effective Software Management

In addition to the growth of the need for software, there are other problems that underlie the expanding costs of mission-critical software. The following problems presented highlight those problems that have caused concern in the DoD.

Dwindling Resources. As the need for software grows, so does the need for software personnel. Unfortunately, the number of trained personnel falls behind the number needed, and as time goes on, the gap will widen (25:42,43). In 1985, the National Science Foundation reported that the data processing community was short between 115,000 and 140,000 systems analysts and programmers, and the DoD predicts that it will be short one million software personnel by 1990 (24:18). Since the civilian sector also has the same problem, this fact may actually be worsening the problem for the defense department, as the civilian companies are hiring personnel away from the government (10:48).

Visibility and Planning. Unfortunately, even after approximately 30 years in the computer era, many senior managers are not very well educated about software (23:17). This lack of knowledge can lead to problems with the visibility and planning of the program. Software is not easily observable, like hardware, and, as a result, can be overlooked by senior management (23:17).

In addition to visibility problems, lack of sufficient planning for software projects can increase costs. Software requirements and specifications are usually poorly defined, and therefore changes are inherent as the project progresses. These changes are considered the most significant cause of cost increases in software projects (24:18).

Lack of Standard Development Process. There is no standard development process for software. A single requirement may result in as many solutions as there are programmers who try to satisfy the requirement (10:50). Software development is more of a creative enterprise than it is an engineering discipline (24:18).

Lack of Standardization in Programming Language and Hardware. Contributing to the lack of a standard development process is the number of diverse programming languages and hardware. The Department of Defense alone uses more than 400 of the estimated 5000 computer languages (24:18). The lack of standardization leads to increased training costs for software personnel.

Strategy to Overcome the Obstacles

The Department of Defense has instituted different programs and written guidelines to try to solve the problems mentioned above. A few of the programs and guidelines are presented here.

Software Engineering Institute. In December 1984, the Department of Defense awarded a \$103 million, five-year contract to Carnegie-Mellon University to create a Software Engineering Institute (SEI) (24:18). The SEI was set up to "investigate the entire software engineering scene in the U.S. to foster new software technologies, and ... to expedite the transition of software technologies into practice" (10:49). The SEI is accomplishing this goal by recruiting corporations and universities to be affiliates in the hopes that collaboration of the "top experts" in the practice will develop useful software engineering tools (24:19).

Software Technology for Adaptable and Reliable Systems. The Software Technology for Adaptable and Reliable Systems (STARS) initiative was a result of a commitment made by the Department of Defense to Congress to institute a software technology initiative (25:43-44). The STARS initiative was instituted in 1983, and is supposed to last for seven years, going through four separate stages in that time (25:44).

The overall STARS goal is to improve productivity while achieving greater system reliability and adaptability (in the face of increasingly demanding requirements) through software development and in-service support processes that are more responsive, predictable, and cost-effective. STARS is concerned with improving both the product (e.g., latent defects per thousand lines of code) and the process (e.g., productivity). (12:25)

Project Bold Stroke. In late 1985, as a result of an Air Staff study on software management, the Air Force instituted Project Bold Stroke (21). Bold Stroke is a "plan to improve software management expertise" (16:1-2). The project has four main objectives:

- I. Create overall Air Force awareness of the criticality of software and computer based technology to information and mission critical systems.

II. Provide software training and education necessary to ensure that the Air Force fully uses the potential available through software and computer-based technology.

III. Survey Air Force software personnel requirements and develop a more comprehensive approach to recruiting and managing military and civilians in this career field.

IV. Project future software personnel requirements with emphasis on the appropriate mix of officers, civilians, NCOs and contractor support. (16:1-2)

Education and Training. Both the Air Force Institute of Technology (AFIT) at Wright-Patterson AFB, Ohio, and the Air Force Systems Command Systems Acquisition School (SAS) at Brooks AFB, Texas, offer courses pertaining to the acquisition of MCCR. The courses are available to personnel in system program offices who occupy positions involved with MCCR acquisition.

AFIT offers at least three courses dealing with MCCR acquisition (2). One course, entitled Mission Critical Computer Resources Acquisition, provides lessons that instruct current and prospective software acquisition managers on topics relative to MCCR acquisition (2:71). The topics covered include hardware, software, the acquisition life cycle, quality assurance, standards, test and evaluation, design and development, and contract surveillance (1).

SAS offers the Computer Resources Acquisition Course. This course is also targeted to personnel who are working in a program office acquiring MCCR. The topics included in this course are the acquisition life cycle, contracts, documentation, standards, Ada, testing, software metrics, production and deployment, and maintenance. (3)

Both schools also offer courses addressing the acquisition life cycle in general.

Ada. In 1975, a Department of Defense working group defined higher-order programming language requirements and initiated the development of Ada, after a review of existing languages found them inadequate (6:42). Ada is the result of an objective to achieve a standard programming language in the Department of Defense (23:24). Ada is different from most other programming languages in that it was developed specifically for embedded computer systems (8:4). In order to ensure that Ada would be a standard language in the DoD, an interim list of DoD-approved higher order languages, which included Ada, was approved as policy in DoD Directive 5000.31 (8:15). Additionally, to prevent the development of many Ada-like languages, "Ada" was approved as a registered trademark of the DoD (8:20).

Program Office Staffing (16:7-3,7-4,7-5,7-7,7-8). To help the program offices with their software management, the Air Force has three primary sources of computer resources expertise. The first two areas presented are career areas for military officers, and the last area presented is a career field for civilian personnel who work for the Air Force.

First, there is the communications-computer systems career area, which encompasses both the communications-electronics and the automated data processing areas. Those people in this career field provide program formulation, engineering, and acquisition support for the Air Force. Officers in this career field have an Air Force specialty code in the 49XX series. The first two digits of the code represent the communications-computer career field, and the last two digits represent the specific specialty that the officer works in under that career field.

Secondly, there is the scientific and development engineering career area. This career area includes the 26XX, the 27XX, and the 28XX series. Three new specialty codes were added to help manage computer resource acquisition. The codes are 2625--Computer Research Scientist, 2736--Computer Systems Acquisition Manager, and 2885--Computer Systems Engineer.

The final source of expertise in computer resources is supplied by civilian personnel who work for the DoD. These people are identified by the series code GS-334, or the Computer Specialist Series. The positions identified by this series will be responsible for "performing the design, implementation, maintenance, and modification of systems that use digital computers to accomplish required work processes" (16:7-3). The series does not include those positions which require full qualification in scientific disciplines encompassing mathematics, engineering, or computer science.

A typical weapon system program office should have some people from the above career areas if the weapon system involves computer resources.

Other Guidelines. To provide guidelines in acquiring software, the Department of the Defense, the Air Force, and the Air Force Systems Command have written regulations and standards. Some of these regulations and standards include DoD-STD-2167, MIL-STD-483A, AFR 800-14, AFSCP 800-43, and AFSCP 800-14.

The first standard, DoD-STD-2167, is titled "Defense System Software Development," and contains the requirements for development of MCCR. It describes a typical system life cycle and the requirements for each phase of the life cycle (13:1). In addition, the standard was developed to

ensure standardized documentation of all software products. This standardization would be beneficial during updating and maintenance of the software. (13)

Military standard 483A establishes requirements for configuration management of systems, equipment, munitions, and computer software (17:1). The standard provides procedures to manage configuration items by identifying and documenting characteristics of the item, controlling changes to those characteristics, and recording the status of the item (17:5).

The Air Force description of what reviews and audits should be done throughout the acquisition life cycle of a weapon system is contained in AFR 800-14. The regulation is a guideline to ensure that the software portion of the system is planned, developed, and acquired alongside the hardware (18:1).

Recognizing that the program managers need help in managing software as well as hardware, a pamphlet on software management indicators was developed by Air Force Systems Command in support of Project Bold Stroke (14:i). The pamphlet, AFSCP 800-43, provides heuristics and standards that can be used to compare against the software development management figures provided by the contractor (14:3).

Subsequent to the development of AFSCP 800-43, Air Force Systems Command also developed AFSCP 800-14. Entitled "Air Force Systems Command Software Quality Indicators," this pamphlet is meant to be used in conjunction with AFSCP 800-43 to promote quality software development (15:3). The pamphlet provides a list of quality indicators, their normal behavior patterns, and guidelines for collecting the indicators' values (15:3).

This is just a small representation of the standards and regulations provided to help the Air Force manage its software programs effectively. A list of other standards and regulations is provided in Appendix A.

Software Quality Assurance.

Software quality assurance is a large topic that has had research focused on it alone; however, it is presented here for familiarization purposes, as it must be taken into account in software projects. Software quality assurance has been described as "the activities necessary to assess and measure the quality of a software product" (4:104). It has also has been described as a program used to "detect, analyze, report, and correct software errors" (19:109). In either case, quality assurance in software projects is important in order to receive software that is usable when delivered by the contractor.

In Air Force programs, there are numerous activities during the life cycle of a program. These activities include reviews, test and evaluation, and independent verification and validation (IV&V) (18). All these activities are planned and scheduled to help ensure that the government gets the product that it wants. These activities also contribute to the quality assurance program for the software. A more detailed explanation of the acquisition life cycle is contained in Appendix C.

Software Safety Management.

The final topic to be covered is software safety management. Software safety management can be defined as "the ability of a computer program and its associated data to avoid system faults that endanger life

or property" (11:148). This topic is very important as the amount of software used to control aircraft systems grows. If an important system fails, both the life of a pilot and the aircraft he is flying may be lost. Software safety management should be considered early in the project since 70 percent of the problems in software systems can be attributed to management and planning deficiencies (11:148).

Summary

The program manager must be aware of the many problems that may endanger the success of the program. Software is just one of the many systems that are a part of the whole program. Software itself has its own set of problems that the program manager has to control. Some of the obstacles to effective software management have been presented, along with some of the strategies and guidelines used to overcome those obstacles.

III. Methodology

This chapter contains the methodology that will be used to answer the research questions posed in Chapter one. The general method used to answer the research questions involved data collection by survey. In this case, the vehicle used to survey will be interviews. The following steps will be done to accomplish the research.

1. Interview guides will be prepared.
2. Program offices will be selected based on pre-determined criteria.
3. The program managers of selected programs will be interviewed to collect their views on the software costs of their respective programs, and who their software experts are if they have any.
4. The identified software experts themselves will be interviewed, and their views on education and job experience will be collected.

Preparation of Interview Questions

Guided interviews will be used when collecting the data. In a guided interview, questions are prepared in advance. The same questions, asked in the same order, are used when interviewing each individual. Using a guided interview ensures that each person will be asked the same questions in the same order. This helps prevent biasing answers differently because of the previous question asked.

The questions for the interview guides will be developed with the objective of answering the research questions. In addition, the following questions will be asked when developing the interview questions:

1. Does the question provide information within the scope of this research?
2. Is the question easily understood?
3. Does the question suggest a certain answer, or is it open-ended enough to let the individuals express their own thoughts?

Selection of Program Offices

The correct selection of the program offices to be interviewed is an important step since selecting the wrong program offices will waste research time and the program manager's time. In choosing the prospective program offices, the following criteria will be applied:

1. The program offices must be from the Aeronautical Systems Division of the Air Force Systems Command.
2. The programs must be involved in software acquisition in some way.
3. The program offices must be accessible to the researcher.
4. The program offices must be willing to participate in the research.

Using the selection criteria, the following program offices are chosen:

- | | |
|-----------------|--------------------------------------|
| 1. ASD/BlM | Directorate of Projects for the B-1B |
| 2. ASD/RWN | Strike System Program Office (SPO) |
| 3. ASD/YWS | Strategic and Airlift Simulator SPO |
| 4. ASD/AEA | Director of Common Avionics |
| 5. ASD/AF/C-17A | Directorate of C-17 Projects |

The selected program offices will be contacted by letter asking for their support. The cover letter will briefly explain the research with

copies of the interview guides attached. Sending the interview guides will allow the prospective interviewees to prepare, in advance, answers to the questions. The program offices will respond to the letter with a list of volunteers for the interviews. The volunteered personnel will then be contacted to set up appointments which are convenient for both interviewer and interviewee. An example of the cover letter and the interview guides are contained in Appendix B.

Interview of Program Managers

An interview will be used since the type of information needed is not readily available except from the program office itself. In order to keep the number of contact points per program to a minimum, the program manager or designated substitute will be interviewed.

The interview guide will be used when interviewing the program managers. The interviews will cover certain topics, which include:

- a. software costs,
- b. staffing and organization,
- c. duties and responsibilities, and
- d. education and training.

The interview of the program managers will answer the following research questions. The research questions are numbered with the same numbers used in the first chapter.

1. What proportion of the overall program costs include software costs?
2. How many of the program offices have some kind of software expertise resident in the office?

3. If the office does not have a software expert in the office, who does the job of ensuring good software design?

4. What other tasks do these people have?

Questions to both the program manager and the software personnel will address the fourth research question. This will be done to try to get as complete information as possible concerning the duties of the software personnel.

One of the problems anticipated is that because of the nature of the program managers' jobs, being able to interview randomly selected program managers would be difficult since they are very busy and travel often. In order to accommodate this problem, a sample of convenience will be used. In anticipation of this problem, one of the criteria for selection will be that the program office be willing to participate in the research. Interviewing those program managers who will be accessible constitutes a sample of convenience. Because of the convenience sample, results of the data collected cannot be statistically generalized to all of the programs, however, since all of the programs have to operate under the same regulations, a logical generalization may be possible.

Interview of Software Personnel

Essential to the performance of the software personnel is the training and education that they receive. The purpose of the interview of the software personnel will be to ascertain what type of educational background and work experience they have, and what type of education they feel they need to have to perform their jobs. In addition, questions concerning what type of work they actually do in the program office will be asked. The interviews will be done using the interview guide, and

only those personnel working for interviewed program managers will be interviewed. If the program office does not have what they consider software personnel, those personnel doing the job of software management will be interviewed, since their views on education and training will help answer the research questions.

The interview questions will cover the following topics:

- a. formal education,
- b. education and training received during employment,
- c. former job experience, and
- d. recommendations for training.

The research questions to be answered from the interviews of software personnel include the following questions. Again, to be consistent, the questions are numbered using the same numbering system as the first chapter.

4. What other tasks do these people have?
5. What type of educational background and work experience do the software personnel have?
6. What other education and experience might be needed?

Data Analysis

Since the nature of the overall problem statement is subjective, an actual statistical test is not appropriate. Rather, the answers to the research questions will be categorized and summaries of the different answers will be presented. None of the answers will be attributed to any individual. Rather, the answers will be combined to present a picture of the interviewees as a whole.

Software Costs. Because of the large differences in size and structure of the chosen program offices, direct comparison of software costs is not appropriate. If software costs are a large percentage of a small program, the software part of the program deserves visibility since it can cause significant program cost overruns. Overall software costs per program will be analyzed in addition to percentages since, in the case of large programs, a small percentage of overall program costs may still be a significant amount of money.

Software Expertise. As discussed earlier, the Air Force has three main areas or sources of computer resources expertise--the communications-computer systems career area and the development engineering career for officers, and the computer specialist series for the civilian personnel. Because of the different sources of software expertise available, no one type of source will be singled out as the resource to have in the program office. Instead, the program managers will be asked if they have any software personnel, and it will be left to the program manager to decide what they consider a software expert. If they respond that they indeed have someone fulfilling the role of software personnel, whether or not they are from one of the three sources described is not an issue.

Ensuring Good Software Design. Since the contractors who develop the weapon system design the software that resides on the system, it is the responsibility of the program office to ensure that the contractor does have good software design. If the program office does have software personnel, these people are the ones who will see that the contractor provides well designed and software. If not, the program office will be

asked who oversees the management of the software portion of the system for the program office.

Tasks and Responsibilities. To get an idea of what the overall responsibilities of the software personnel are, questions addressing duties and responsibilities will be asked of both the program managers and the software personnel. The responses to the questions will be summarized and listed by program office since each office is organized differently.

Education, Training, and Work Experience. Questions addressing formal education, training, and work experience will be asked of both the program managers and the software personnel. Results of these questions will be summarized and used to answer the last two research questions.

IV. Research Observations

This chapter contains the resulting views collected during interviews with the selected program offices. The collection and analysis of data followed a pre-determined methodology. After the interview guides were complete, program offices were selected and contacted. Those individuals who volunteered to be interviewed were scheduled for an interview and the results of those interviews were analyzed as possible answers to the research questions. Each program office, except ASD/RWN, provided one person from program management and two software personnel. ASD/RWN was only able to provide one software person. Therefore, there were a total of fourteen persons interviewed--five from program management, and nine software personnel.

The type of weapon system a System Program Office (SPO) is procuring may determine the organizational structure and the assignment of personnel within that organization. Before discussing the results of the interviews, a short description of each program office is presented. The terms "program office" and "SPO" are used interchangeably throughout the rest of this document. Additionally, since all of the program offices are in ASD, they may be referred to by their "three-letter" symbol by dropping the "ASD/" part of their office symbol.

ASD/B1, or the B-1B SPO, is what is termed as a "super SPO." In other words, the main responsibility of the B-1B SPO is the procurement of one complete weapon system, in this case the B-1B bomber, and all of its support equipment and facilities. All members of that organization

are dedicated to providing support in acquiring systems and subsystems of that one aircraft.

The Strike SPO, ASD/RWN, is a smaller program office, residing in the same organization as other small program offices. Its main responsibility is to procure a system that can reside on one or more different types of aircraft, in support of that aircraft's overall mission. Personnel of the organization may work on one program, or share time on other small programs for which the organization is responsible.

The third program office, ASD/YWS, is also a small program office, residing in the same organization as other small program offices. The main responsibility of this SPO is to procure aircrew training systems and simulators that help teach aircrews to fly aircraft that are normally assigned to Strategic Air Command. Because the program office is one of several in the same organization, it too has to share some of its personnel with other program offices in that organization.

The Common Avionics SPO, ASD/AEA, is the third small program office residing in the same organization as other program offices. This program office procures standardized or common systems that are used on one or more different types of aircraft. The systems help the aircraft perform their missions. AEA also shares some of its personnel with other program offices.

Finally, the last program office interviewed, the C-17 SPO can also be considered a "super SPO." Although the organization to which the C-17 SPO belongs has program offices for more than one system, the personnel assigned to this program are separated from the others by being located in a separate building. Currently, the program office is in the process

of becoming its own organization. It is responsible for the procurement of the C-17 transport aircraft and all of its associated support equipment.

Software Costs

The first research question asked, "What proportion of the overall program costs include software costs?" To get an answer to this research question, three questions were asked of personnel working in program management at each of the SPOs. The three questions were:

1. What do you estimate are your software costs for your program?
2. What is the total cost of your program?
3. What do you do to ensure that software costs are kept to a minimum?

Table 1 shows the results of these questions for each of the program offices.

Table 1. Results of Research Question 1

<u>SPO</u>	<u>Total Cost of Program (\$)</u>	<u>Software Costs (Estimated % of Total)</u>	<u>Estimated Software Costs (\$)</u>
B-1B	20.5 Billion	5 - 10	1.03 - 2.05 Billion
RWN	3.8 Billion	1	45 Million
YWS	300 Million	50 - 70	200 - 220 Million
AEA	100,000/unit	20 - 30	20,000 - 30,000
C-17	34 Billion	*	*

* - Estimates of software costs could not be given since the program was not far enough into the acquisition life cycle.

The software costs presented are only "best guess" estimates given by the program managers. The contract types awarded to the prime contractors were fixed price contracts. In other words, an amount was negotiated between the government and the contractor and the contractor is obligated to deliver the specified system for that amount of money. Since the price included hardware, software and all other necessary items such as labor and administrative costs, it was not possible for the program managers to break out exact costs for the software. Along the same lines, the managers did not really have an answer to the third question except to say that since the contracts were fixed price, the contractor was bound by the contract to deliver the software included in the system for the negotiated price of the overall system.

The software costs do amount to a large percentage of the overall program costs for two of the program offices. For the B-1B SPO and RWN, however, even though the percentages of the software costs are lower, the actual amounts are large. The estimated software cost for RWN is lower than it probably should be since the \$45 million includes only the cost of manpower used to develop the software. It does not include the costs for quality assurance, configuration management, or the costs for changing the software.

Software Expertise

To answer the question, "How many of the program offices have some kind of software expertise resident in the office," the following series of questions were asked of the program managers.

1. Do you have software personnel in your organization? If not, do you need software personnel? Who do you have doing the job of the software personnel in the mean time?
2. Where do you use your software personnel in your organization?
3. How many people are permanently assigned as software personnel?
4. How many people, in total, are assigned to the organization?

The results of these questions are presented in Table 2. All of the program offices interviewed had what they considered to be software personnel. YWS, which is considered to have a software intensive program due to the simulators it is procuring, had a greater proportion of software personnel to the overall total of people assigned to the program at 40%. The total number however, only includes people directly assigned to that program. Recall that the Strategic and Airlift SPO is just one program office in an organization of many. There are other personnel matrixed in to handle administrative tasks, such as contracting, configuration control, and other functions.

Table 2. Software Personnel in Program Offices

<u>SPO</u>	<u>Software Personnel (Y/N)</u>	<u>Number of Software Personnel</u>	<u>Total Number of Personnel</u>	<u>Percentage</u>
B-1B	Y	10	250	4
RWN	Y	4	70 - 75	2 - 3
YWS	Y	4	10	40
AEA	Y	2	50	4
C-17	Y	3	135	2

In all of the SPOs, the engineers and some of the software personnel come from the ASD's Deputy for Engineering (ASD/EN) (5). Therefore, to get the required software support personnel, the program office must go to ASD/EN and request support. The personnel may be then assigned to the SPO's organization, but are still resources of ASD/EN. To further complicate matters, in the smaller SPOs where there are more than one program office in the same organization, the engineers and software personnel may be assigned work from more than one program. In all of the small SPOs interviewed, at least one software person was dedicated to that program, and other personnel, who had work from other programs, were available when needed.

Ensuring Good Software Design

The third research question was, "If the office does not have a software expert in the office, who does the job of ensuring good software design?" Since all of the program offices interviewed had someone that they considered a software expert, this research question did not apply. Additionally, four of the program offices interviewed had some kind of outside support to provide independent verification and validation (IV&V) of the software and/or its documentation. The C-17 SPO had not yet progressed far enough in the acquisition life cycle to have software products that needed IV&V, and the prime contractor was performing verification and validation of the software its subcontractors had completed.

Tasks and Responsibilities

The objective of the fourth research question was to find out what other tasks the software personnel have. To answer this question, the

duties and responsibilities of the software personnel are presented. Since each organization has its own procedures, the duties and responsibilities for each SPO will be discussed separately. Both the program managers and the software personnel were asked questions concerning this subject. The program management personnel were asked the following questions:

1. What are the duties of your software personnel?
2. Who reviews your software technical documents?
3. What type of procedures do you have to ensure adequate review?
4. Who conducts the reviews and audits of the software?

The software personnel were asked the following question concerning their duties and responsibilities:

1. What are your duties in this program?

B-1B SPO. The software personnel in the B-1B SPO are the technical representatives of the program. They initiate, staff, and brief software change requests when needed, and oversee the contracts pertaining to the software packages assigned to them. The review of the technical documents are done by the software personnel, but because of time constraints, only a "top-level" review is accomplished.

The audits and reviews of the software are taken care of at the Functional Configuration Audit, the Physical Configuration Audit, the engineering review (or the Preliminary Design Review), and the configuration review (or Critical Design Review). The configuration and data management directorate of the SPO is responsible for setting up the meetings and publishing the minutes.

ASD/RWN. In the Strike SPO, the software personnel provide services to include review of the documentation, audits, and participation in the testing of the systems. In addition to the software personnel assigned to the SPO, RWN has a contract with a private company to provide independent verification and validation. The company provides in-depth review of the technical documents, while the software personnel also review the documents. This procedure is also followed during audits.

ASD/YWS. YWS also has an independent verification and validation contractor. Their job is to review technical documents for consistency, completeness, and correctness. The software personnel in this SPO are responsible for making sure that the software meets specifications, and that it is designed, coded, and documented in accordance with standards. In other words, the SPO personnel check for technical correctness, while the IV&V contractor checks the written documents to make sure that they are written correctly. The software personnel are also responsible for reviewing the software. They ensure that the software is documented according to DoD-STD-2167, and that the software unit development folders are kept up to date.

The SPO uses a computer system to track documents for when they are due from the contractor, and where the documents are in the organization for review. The configuration and data management directorate is responsible for keeping the system up to date. They are also responsible for conducting the functional and physical configuration audits.

ASD/AEA. During the interview with the program manager, he enumerated the following duties and responsibilities of his software personnel:

- help write software performance specifications,
- identify what requirements need to be allocated for software,
- help estimate software costs,
- help write statements of work for contracts,
- provide technical advice to program management,
- monitor the contractor's performance of the contract with respect to all software development and testing activities, and
- participate in approving test plans and test procedures, and in evaluating test results.

The software personnel are responsible for reviewing the technical documents and for running the software audits and reviews. There is no formal procedure for ensuring adequate review, and the personnel rely on their training when performing the reviews.

C-17 SP0. The software management support for the C-17 SP0 is divided into two different groups. There is a group of people who work with the program management. They are not matrixed into the SP0 from ASD/EN, and are the program manager's experts on software. They head up the program management team in the software area and are active in the computer resources working group. The SP0 is also procuring a management information system (MIS) and these software personnel are responsible for overseeing that process. The second group of software personnel are matrixed into the SP0 from ASD/EN and are mainly responsible for portions of the software that reside on automated test equipment.

Both groups are responsible for reviewing technical documents, and there are no formal procedures for adequate review. An office of primary responsibility is designated for the review of a document, and that office is held responsible for adequate review. Software reviews and

audits are held by the prime contractor since the software is subcontracted out by the prime contractor. In other words, the subcontractor writes the software and delivers it to the prime contractor. The prime contractor reviews the software, and the SPO personnel are allowed to attend the reviews. The SPO monitors the procedures and performance of the prime contractor.

Education, Training, and Work Experience

The fifth research question asked, "What type of educational background and work experience do these software experts have?" To answer this question, the software personnel were asked six different questions regarding their jobs, past and present, and the education and training they had received. The questions asked were as follows.

1. What other programs have you worked on?
2. How much do you rely on your previous work experience in your current job?
3. What type of educational background do you have?
4. How has this education been beneficial to your job?
5. What type of formal training have you had in connection with your job?
6. How has this training been beneficial to your job?

The answers to the fourth and sixth questions are used to form recommendations for training and education. The answers to the other questions form the basis for a possible answer to the fifth research question. Table 3 contains information regarding the education and work experience of each person. It also has their recommendations on education and training.

Table 3. Individual Views on Education, Training, and Work Experience

(1) Previous Work Experience	(2) Formal Education (Note 1.)	(3) Recommended Education (Note 2.)	(4) Recommended Training (Note 3.)
1. Private Industry	Elec Engr	A,B	1,2,6
2. None	Comp Sci	B,C	1,2,9
3. Avionics "hot bench"	Engr Phys	A,C	4,10
4. Program Office	Elec Engr	D	12
5. Program Office	Elec Engr (working on M.S. Elec Engr)	F	1
6. Program Office	Elec Engr	D	1
7. Branch Chief ASD/ENASC	B.S. Elec Engr M.S. Elec Engr M.S. Engr Mgt	B,C	1,3
8. Private Industry Co-op w/Government	Engr Phys	E	1,2,3,7, 11,13,14
9. Computer Center	Comp Sci (working on M.B.A.)	A	1,2,5,8

NOTE 1. Comp Sci - Computer Science; Elec Engr - Electrical Engineering; Engr Mgt - Engineering Management; Engr Phys - Engineering Physics.

NOTE 2. A - Computer Engineering; B - Computer Science w/hardware courses; C - Electrical Engineering w/software courses; D - Engineering; E - Business w/minor in computers; F - Chemical Engineering.

NOTE 3. 1 - Systems Acquisition; 2 - Computer Resources Acquisition Course; 3 - Contracting; 4 - Ada; 5 - Configuration Management; 6 - DoD-STD-2167; 7 - Jovial; 8 - Logistics Support; 9 - RADAR; 10 - Real-time Programming; 11 - Reliability of Hardware and Software; 12 - Software Engineering; 13 - Software Quality Assurance; 14 - 1750 Processors.

Education. Of the nine software personnel interviewed, two were educated in engineering physics, five held degrees in electrical engineering, and two people had a degrees in computer science. In addition, one of people who held an undergraduate degree in electrical engineering held a graduate degree in electrical engineering and another graduate degree in engineering management. Two others were working towards Masters degrees in Business Administration, and one person was close to completing his graduate degree in electrical engineering. Of the two people working on their MBAs, one held a degree in engineering physics, and the other held a degree in computer science. The person working on his graduate degree in electrical engineering already held a baccalaureate degree in the same subject.

Training. Since the interviewees were allowed to list the different training classes they had attended when they answered the question regarding training, there are more than nine different answers. A summary of the different training subjects and the number of responses pertaining to each subject is contained in Table 4. The subjects are ordered by the number of responses pertaining to them from highest to lowest. Those subjects with ties are ordered within themselves in alphabetical order.

In addition to the questions about training asked of the software personnel, the program managers were asked what type of training program they had for their personnel. All of them replied that they had no formalized training program, and that they relied on ASD/EN to supply all the training necessary before the engineers and software people were assigned to the SPO. That did not mean, however, that the program office

would not send their people to any training. If a course was available, and the program office could afford both the time and the money, their engineers and software people were allowed to attend the course.

Table 4. Training Attended

<u>Subject</u>	<u>:: of Responses</u>
Computer Resources Acquisition Course (CRAC)	5
Systems Acquisition Courses (SYS 100, 200, SAS)	5
Ada (Programming Language)	3
Software Quality Assurance	3
Software Engineering	2
Cost Estimating	1
DoD-STD-2167	1
Hardware/Architecture	1
Jovial (Programming Language)	1
Real-time Systems	1
Reliability	1
System Software	1

The training that the software personnel, who came from ASD/EN, received was not necessarily the same for each person. Training periods in EN lasted anywhere from two weeks to two years. On the extremes, one person said that he was in EN for a week or two when a requirement for a software person came up, and he was assigned to a program office. The other extreme involved a person who spent two years working on an avionics "hot bench." Those who fell in the middle spent an average of six months in EN, and attended the Computer Resources Acquisition Course, among other training courses.

Not all of the software personnel were matrixed into the SPOs from EN. Two of the software personnel in the C-17 SPO were not from EN. Therefore, they did not receive any of the training that EN provides to its engineers.

Work Experience. Only three of the nine software personnel interviewed had previous program experience. Of those three, only one person did not rely on the previous experience in his current job. His previous experience was in source selection for another program, and he felt that he never used that experience when conducting his duties.

The two remaining persons were from small SPOs and had been in other SPOs within the same organization. Both said they relied on their previous work experience in their current job, but not to the same degree. The first person said he relied "95% on previous experience" in doing his current job. The other person said he rarely needed his previous engineering experience, but when he did, he needed quite a bit of his engineering expertise. In his own words, he relied on his previous experience "heavily, but not often."

Of those who had not worked on other programs, four had previous work experiences in other than weapon system program offices. The first person had worked for a short time in the private sector for a defense contractor. He felt that this experience helped when he prepared contract proposals and other contracting documents. The second person had some experience with industry and "co-op" experience with the government while attending college. He felt that he had built his knowledge from the experience gained from those previous jobs since his education was in engineering physics.

The third person had previously been a communications-computer officer and had worked in a computer center as a requirements and plans officer. He felt that this experience helped him in his current job since the SPO was acquiring a management information system (MIS). The

basic understanding of rules and regulations regarding the acquisition of an MIS as well as buying computer equipment was some of the knowledge he had gained at the computer center.

Finally, the fourth person worked in an avionics facility on an Ada avionics hot bench within ASD/EN for two years before coming into his present job. In his previous job, he had learned how to write and test software for the same type of hardware that is used on avionics equipment. He felt that this type of experience was "incredibly valuable" to him in his current job. He had only been on his current job for six months at the time he was interviewed, and he felt that he was very well "on top" of his job, and that he would not be without the experience he gained in his previous job. He felt that his education in engineering physics had taught him to approach each problem from an engineering perspective, and that perspective helped him to learn about software easier.

Education, Training, and Work Experience Needed

The objective of the last research question was to find out what other education and experience might be needed. To answer the research question, the software personnel were asked the following questions.

1. What type of training do you feel you need but have not been able to get?
2. What type of education do you recommend for your job?
3. What type of previous work experience do you recommend?
4. What type of training programs do you recommend?

The first and fourth questions were asked to get an idea of what type of training the software personnel felt they needed to do their

jobs. The other questions were asked for the same reason pertaining to their respective subjects.

Education. In addition to the question asked of the software personnel, the program managers were asked what they recommended as a good educational background for their software people. A summary of their answers is contained in Table 5. The recommended education is listed by subject and the number of responses pertaining to that response.

Table 5. Recommended Education

<u>Subject</u>	<u># of Responses</u>
Computer Engineering	6
Computer Science with Hardware courses	6
Electrical Engineering w/Software courses	4
Engineering	3
Business with minor in computers	1
Chemical Engineering	1
Computer Science with Math	1

NOTE. The numbers do not add up to equal the fourteen persons interviewed since they were allowed to list any number of educational subjects.

The computer engineering degree consists of courses in both computer science and electrical engineering. Having an education in both software and hardware was important to the majority of those interviewed. Nine of the fourteen people interviewed responded one or more of the top three responses.

Three people responded that engineering was a recommended educational background, while one person responded that chemical engineering

was recommended. All four of these people contended that the discipline and way of approaching a problem learned in an engineering education was enough background for anyone to be a software manager. They maintained that the knowledge in software engineering and the other education needed to accomplish the job could be learned in training available through the Air Force and other agencies.

Training. In their responses to recommended training, the interviewees were allowed to list any number of training subjects. The subjects and the number of responses for each subject are listed in Table 6. Because of the numerous responses each person gave, the total number of responses does not add up to nine. The subjects are listed in order of the number of responses given for that subject from highest to lowest.

Table 6. Recommended Training

<u>Subject</u>	<u># of Responses</u>
Systems Acquisition	7
Computer Resources Acquisition Course (CRAC)	4
Contracting (Writing Statements of Work, etc.)	2
Ada	1
Configuration Management	1
DoD-STD-2167	1
Jovial (Programming Language)	1
Logistics Support	1
RADAR	1
Real-time Programming	1
Reliability of Hardware and Software	1
Software Engineering	1
Software Quality Assurance	1
1750 Processors	1

When asked what type of training they felt they needed, but had not been able to get, there were four responses for training in the Ada

programming language, and four responses for training in systems acquisition.

Work Experience. Even those people without any previous work experience were allowed to recommend what they perceived as a good job to have before coming into their current position. A summary list of types of work experience follows. They are not listed in any particular order.

- Working in the private sector for a defense contractor
- Working in another SPO on another program
- Getting "hands-on" experience with developing computer systems on an avionics hot bench
- Working in an organization considered to be a prospective user of the system that the SPO is procuring
- Being senior in rank with previous program office experience
- Working on other small programs from start to finish
- Having previous experience in engineering, a computer center, a program control office, and configuration management

Other Observations

One of the questions that was asked of the software personnel, but did not really fall under just one of the research questions was, "How much knowledge in software engineering is needed to accomplish your responsibilities?" Three of the software personnel responded that they needed their knowledge of software engineering to understand what the contractor was doing, and to understand documentation. The rest responded that they needed a little knowledge of software engineering, but were really learning what to do in their job through experience.

Another observation made was that the two software personnel who did not have a degree in either electrical engineering or computer science,

recommended and desired to take courses in computer hardware and programming languages. (See columns 2 and 4 of Table 3.)

Third, even though the SPOs had software personnel assigned, all of the program managers felt that they could use more software personnel. The C-17 SPO was in the process of expanding the number of software personnel and the number of hardware engineers. The program management knew that they would need more than three people to manage the acquisition of all of the software related to a large transport aircraft.

The last observation made was that, of the three sources of computer resources personnel, only two of the nine personnel came from any of those sources. Both of them came from one source in particular, which is included in the development engineering career area. They both had the specialty code of 2625--Computer Research Scientist. The other people also came from the development engineering career area, but did not have the specialty codes identified as a source of computer resources expertise. None of the software personnel interviewed were from the communications-computer systems career area or the civilian computer specialist series at the time of the interviews. However, one of the Computer Research Scientists was previously a communications-computer systems officer.

Finally, even though this was not considered to be an observation, those people who were interviewed provided additional comments. They expressed concern over the length of training since the SPOs cannot afford to have personnel gone from the office to attend three weeks of training. Additional comments are provided in Appendix D.

V. Conclusions and Recommendations

In order to tie the research to some useful form of information, this final chapter presents conclusions to the research questions and recommendations for improvement. This research does not provide an overall solution to the questions. Rather it presents one contribution to the solution.

Research Summary

Even though the SPOs were of different sizes, and were responsible for programs ranging from avionics to total aircraft systems, they were bounded by the same rules and regulations. Because of these rules and regulations, the SPOs operated similarly. They did differ in those cases where different programs determined costs, and different management styles determined different delineation of responsibilities. The following is a short summary of the research and a conclusion for each of the research questions.

Software Costs. The software costs did amount to large percentages in two of the programs. For another two, even though the percentages were not as large, the estimated costs were large sums of money in millions and billions of dollars. Software can no longer be ignored. The cost of software may eventually determine the price tags of weapon systems.

Because of the nature of the type of contracts that the SPOs were using, they were not able to control the cost of the software separately. As long as the contractor delivered the required system for the negotiated price, the contract would be satisfied.

Software Expertise. All of the program offices had someone that was considered a software expert. The majority of these people were engineers with some training in software.

ASD/YWS, the Strategic and Airlift Simulator SPO, had the largest proportion of software costs, and software personnel. This large proportion was because of the nature of the program. The SPO was responsible for acquiring a simulator that would be used to train aircrews of a specific aircraft. Simulator systems are software intensive since it is the software that simulates the different conditions that aircraft encounter.

The Common Avionics SPO, ASD/AEA, had the next largest proportion of software costs, but did not have a large percentage of software personnel. Its percentage was close to, or the same as, the remaining SPOs.

Even though the program offices realized the importance of software in their respective systems, they were not staffing a large proportion of software personnel in the offices. This understaffing may be attributed to the shortage of qualified software personnel in the Air Force.

Ensuring Good Software Design. All of the program offices had software personnel who monitored the contractor's performance of their contracts. The contractors were responsible for good software design. The program offices were concerned with ensuring that the software performed according to specifications. It seems that no one in the program offices had the time or personnel available to ensure good software design.

Tasks and Responsibilities. Even though some of the duties and responsibilities differed from SPO to SPO, all of their software personnel were responsible for reviewing the technical documents pertaining to the software portions of their systems. They made sure that the documents and software items were delivered on time and according to technical specifications, and they attended the reviews of the software.

Education, Training, and Work Experience. The majority of the software personnel interviewed had educational degrees in electrical engineering with some courses in software. Additionally, most of them had some training in systems acquisition. Finally, only three of them had previous SPO experience.

Of those people who came to the program offices from ASD/EN, their training program in EN was not consistent among them. The amount of time spent in EN varied along with the type of training each person received.

Education, Training, and Work Experience Needed. Most of the program managers and software personnel interviewed recommended that education in both the hardware and software of computers is the best background for the job of software management. The most recommended training courses included systems acquisition courses and the Computer Resources Acquisition Course. Finally, most of the software personnel said that previous program office experience would have helped them in their current jobs.

Recommendations

These recommendations were compiled after analyzing what type of education, training, and work experience was most recommended by the program managers and software personnel interviewed.

Education. The recommended educational background for the software personnel is an education in both the hardware and software of a computer system. This type of education is usually called computer engineering and consists of courses in software engineering and computer architecture. Understanding both the software and the computer system on which it runs will help the software person to better evaluate the specifications, documentation, and test reports of the computer resources.

Training. The recommended training includes courses in both the acquisition of computer resources and system acquisition. The courses in computer resource acquisition would familiarize the software personnel in documentation, contract management, and details that pertain only to computer resources. The system acquisition courses would familiarize the software personnel with the acquisition life cycle, and enable them to see how the software portion of the program fits in with the acquisition of the whole weapon system.

Additional training should be available to the software personnel after being assigned to a program office. These courses will help them keep up with the changing technology. These courses should not be longer than five days in duration, since most program offices cannot afford to have personnel gone too long for training.

Work Experience. If possible, before being assigned to a program office, the software personnel should have some experience in working in

a program office. This could be done while the personnel are still being trained at ASD/EN. They could be temporarily assigned with an experienced person to work on a program for a short period of time. This would provide some insight as to how a program office operates.

All of these recommendations are possible only if the time, training, and personnel are available, and many times the opposite is true. However, if the Air Force is interested in having good software management in the program offices, these recommendations, based on current views, are what the Air Force should follow.

Problems Encountered

As anticipated, coordinating times when program office personnel would be available for interview was very difficult. Most of the software personnel were available, but a few were out of town when their offices were contacted. The program managers were a bit more difficult contact. Four of the five were out of town quite a bit, or had other meetings to schedule around when they were in town. This difficulty in setting up interview appointments extended the total amount of time needed to interview all of the people. Even though there were only fourteen people interviewed and each interview lasted from twenty minutes to an hour, the total time to complete all of the interviews took over six weeks.

Secondly, because software is not priced separately in the contracts, it was very difficult for the program offices to offer anything but best guess estimates of the software costs. This problem led to difficulty in accurately assessing the proportion of program costs dedicated to software.

Further Research

Further research into the management of software and software costs is recommended. Approaches to research in these two areas are discussed.

Management of Software. Further research into what the software personnel actually have to do on a day to day basis is recommended. A listing of all of the software personnel could be obtained from ASD/EN and a random sample could be generated. A survey instrument in the form of a questionnaire could be sent to the sample. The questionnaire would contain detailed questions asking about time spent with contracting documents, software documentation, and actually looking at programming code. Other questions regarding knowledge needed in hardware and software could be asked. And finally, questions pertaining to decision making on matters concerning computer resources could be asked. From the answers to the questions, more accurate recommendations regarding educational background and training could be made.

Software Costs. Until the cost of software is broken out separately, it will be difficult to do any more research on the costs. However, once the costs are broken out, analysis and comparisons between different program offices and how they control the costs of software could be a basis for research.

Conclusion

Once the Air Force understands how much of its weapon systems depend on software, and develops the resources to address the growing dependence, it can begin to control the cost of software. Research into those resources can help identify how the Air Force can approach the problem.

This research addressed personnel resources--whether or not there was a need for them, and what type of education and work experience they should have. Personnel with a computer engineering degree, training in systems and computer resource acquisition, and some program office experience, will provide one approach to the problem of controlling computer resources in weapon systems.

Appendix A: Directives, Standards, and Regulations

Department of Defense Directives/Instructions

DODD 4120.3	Defense Standardization and Specification Program
DODD 4155.1	Quality Program
DODD 4155.19	NATO Quality Assurance
DODD 5000.1	Major System Acquisition
DODD 5000.2	Major System Acquisition Process
DODD 5000.3	Test and Evaluation
DODD 5000.29	Management of Computer Resources in Major Defense Systems
DODD 5000.31	Interim List of DoD Approved High Order Programming Languages (HOL)
DODD 5000.35	Defense Acquisition Regulatory System
DODL 5010.12	Acquisition Management Systems and Data Requirements Control List (AMSDL)
DODD 5010.19	Configuration Management
DODD 5200.28	Security Requirement for Automatic Data Processing (ADP) Systems
DODI 7041.3	Economic Analysis and Program Evaluation for Resource Management

Standards and Specifications

MIL-STD-109B	Quality Assurance Terms and Definitions
DOD-STD-480A	Configuration Control-Engineering Changes, Deviations and Waivers
MIL-STD-481A	Configuration Control-Engineering Changes (Short Form)
MIL-STD-482A	Configuration Status Accounting Data Elements and Related Features

MIL-STD-483A	Configuration Management Practices for Systems, Equipment, Munitions, and Computer Programs
MIL-STD-490A	Specification Practices
MIL-STD-499A	Engineering Management
MIL-STD-721C	Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors and Safety
MIL-STD-881A	Work Breakdown Structures for Defense Material Items
MIL-STD-1521B	Technical Reviews and Audits for Systems, Equipment and Computer Programs
MIL-STD-1535A	Supplier Quality Assurance Program Requirements
MIL-STD-1553B	Aircraft Internal Time Division Command/Response Multiplex Data Bus
MIL-STD-1589C	JOVIAL (J73)
MIL-STD-1750A	Airborne Computer Instruction Set Architecture
MIL-STD-1760A	Aircraft/Store Electrical Interconnection System
MIL-STD-1815A	ADA Programming Language
MIL-STD-1862B	NEBULA Instruction Set Architecture
DOD-STD-2167	Defense System Software Development
MIL-Q-9858A	Quality Program Requirements
MIL-S-52779A	Quality Assurance Program Requirements
MIL-S-83490	Specifications, Types and Forms
MIL-HDBK-334	Evaluation of a Contractor's Software Quality Assurance Program

Regulations, Manuals, and Pamphlets

AFR 70-1	Procurement of AF Assigned Items Under the DoD Coordinated Procurement Program
AFR 70-18	Local Purchase Program (AFSC Supplement)
AFR 80-14	Test and Evaluation
AFR 700-1	Managing Air Force Communications Computer Systems

AFR 700-2	Information Systems Planning
AFR 700-3	Information Systems Program Management and Acquisition
AFR 700-4, Vol I	Information Systems Program Management
AFR 700-4, Vol II	Information Systems Acquisition and Major Automated Information Systems Review Requirements
AFR 800-2	Acquisition Program Management
AFR 800-3	Engineering for Defense Systems
AFR 800-12	Acquisition of Support Equipment
AFR 800-14	Lifecycle Management of Computer Resources in Systems
AFR 800-17	Work Breakdown Structure (WBS) for Defense Materiel Items
AFR 800-28	Air Force Policy on Avionics Acquisition and Support
AFLCR 66-27	Automated Support of ATE Software
AFLCR 66-37	Management of Automated Test Systems
AFCMDR 70-16	Supporting Contract Administration
AFCMDR 70-24	Subcontract Management Program
AFCMDR 178-1	Contractor Management System Evaluation Program
AFCMDR 800-1	Acquisition Management-Contract Management Engineering
AFCMDR 800-3	Embedded Computer Resources
AFSCR/AFLCR 80-17	AF Engineering Responsibility for Systems and Equipment
AFSCM/AFLCM 375-7	Configuration Management for Systems, Equipment, Munitions, and Computer Programs
AFSCP 800-14	Air Force Systems Command Software Quality Indicators
AFSCR 800-14	Management of Computer Resources in Systems
AFSCP 800-43	Air Force Systems Command Software Management Indicators

Appendix B: Sample Cover Letter and Interview Guides



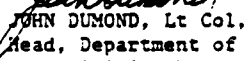
DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OH 45433-6583

REPLY TO LSY (Capt Roger Davis, 255-4845)
ATTN OF
SUBJECT Software Personnel Requirements Research Interview

11 MAY 1987

TO ASD/

1. Lieutenant Cynthia L.A. Norman, a master's degree candidate in the Systems Management Program at the Air Force Institute of Technology (AFIT), is conducting research on the education, skills, and experience requirements for software management personnel assigned to program offices. Upon completion, she will be able to provide recommendations for software personnel support in the program offices.
2. To achieve her objectives, Lt Norman needs to interview someone from program management, as well as individuals in your organization who provide software management support on your program. Attachments 1 and 2 list the information she would like from you and your software people, respectively. Could Lt Norman interview you or your deputy and two other qualified software people in your organization? The interviews should take about 30 minutes for each person. If you are willing to help, would you please provide the names and phone numbers back to me by 1 June 1987. Lt Norman will then contact these individuals directly to set up an appointment. In addition to the interview, if you could provide a copy of your organizational chart, it would help her research efforts.
3. Thank you for your help in this effort. If you have any questions, feel free to contact Lt Norman at 56569 or her thesis advisor, Capt Roger Davis, AFIT/LSY.


JOHN DUMOND, Lt Col, USAF
Head, Department of System
Acquisition Management
School of Systems and Logistics

- 2 Atchs
1. Program Manager
Interview Guide
 2. Software Personnel
Interview Guide

STRENGTH THROUGH KNOWLEDGE

Interview Guide
Program Managers

Background

1. Name.
2. Position.
3. Program.
4. How many years have you been assigned to this program?

Software Costs

5. What do you estimate are your software costs for your program?
6. What is the total cost of your program?
7. What do you do to ensure that software costs are kept to a minimum?

Staffing and Organization

8. Do you have software personnel in your organization? If not, do you need software personnel? Who do you have doing the job of the software personnel in the mean time?
9. Where do you use your software personnel in your organization?
10. How many people are permanently assigned as software personnel?
11. How many people, in total, are assigned to the organization?

Duties and Responsibilities

12. What are the duties of your software personnel?
13. Who reviews your software technical documents?

Documents may include:

- a. Technical Proposal
- b. System specifications and/or requirements
- c. Computer resource utilization reports
- d. Software development manning profiles
- e. Engineering change proposals
- f. Development, test, and integration schedules
- g. Cost reports (CPR or C/SSR)

14. What type of procedures do you have to ensure adequate review?

15. Who conducts the reviews and audits of the software?

Education and Training

16. What type of educational background do you require of your software personnel?

17. What type of training program do you have for your software personnel?

Conclusion

18. What else would you like to add?

19. What questions may I answer for you?

20. Do you have any additional materials that might help in my research?

Interview Guide
Software Personnel

Background

1. Name.
2. Position.
3. Program.
4. How many years have you been assigned to this program?

Work Experience

5. What are your duties in this program?
6. How much knowledge in software engineering is needed to accomplish your responsibilities?
7. What other programs have you worked on?
8. How much do you rely on your previous work experience in your current job?

Education and Training

9. What type of educational background do you have?
10. How has this education been beneficial to your job?
11. What type of formal training have you had in connection with your job?
12. How has this training been beneficial to your job?

Personal Views

13. What type of training do you feel you need but have not been able to get?
14. What type of education do you recommend for your job?
15. What type of previous work experience do you recommend?
16. What type of training programs would you recommend?

Conclusion

17. What else would you like to add?
18. What questions may I answer for you?
19. Do you have any additional materials that might help in my research?

Appendix C: The Acquisition Life Cycle

The acquisition life cycle consist of four phases: concept exploration, demonstration and validation, full-scale development, and production and deployment. Certain prescribed activities take place during each phase. Proper management of hardware and software activities during the phases is important. This appendix addresses the software portion of the acquisition life cycle and how it relates to the hardware acquisition. (See Figure 2.)

Concept Exploration

The first phase, concept exploration, is spent refining solutions, performing studies, and developing alternatives for a required operational capability (13:61; 18:12). Some of the types of studies performed during concept exploration include requirements refinement, operational concept analysis, tradeoff and optimization studies, feasibility studies, and risk analysis.

During this phase, a Computer Resources Working Group (CRWG) is formed. The CRWG is responsible for developing an initial Computer Resources Life Cycle Management Plan (CRLCMP), evaluating alternatives for computer resources support, identifying unique software quality requirements, and evaluating hardware, programming languages, software tools, and software development approaches (18:12). Preliminary system specifications and an initial Test and Evaluation Master Plan (TEMP) should be available at the end of concept exploration, and a system requirements review (SRR) should be accomplished (13:64; 18:12).

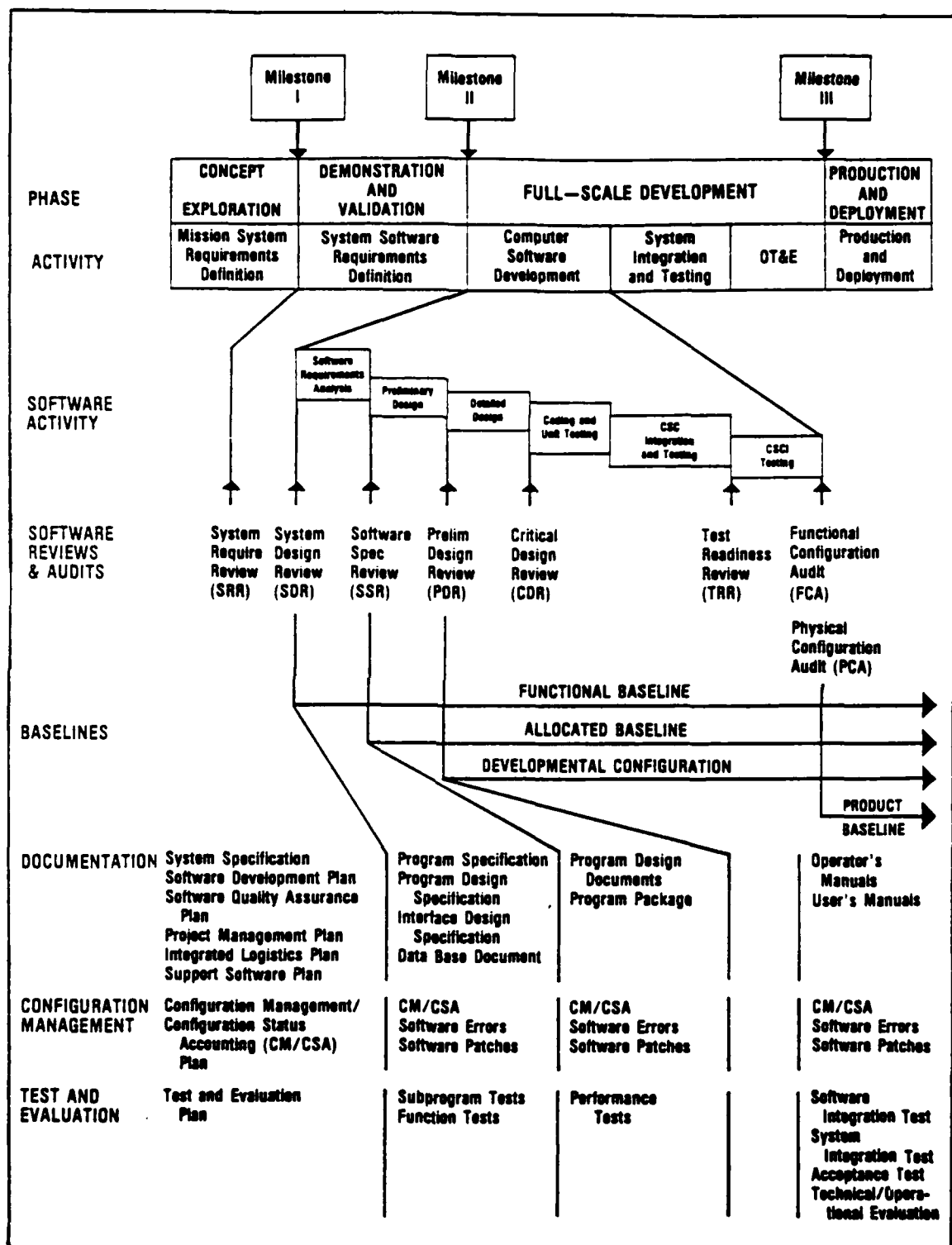


Figure 2. Software Development Life Cycle (9:32)

Demonstration and Validation

The objective of the demonstration and validation phase is to validate a choice of alternatives so that a decision can be made whether or not to continue the project (13:64; 18:13). During this phase requirements are further broken down until the entire system is described and engineering studies are done on the requirements (18:13). The engineering studies include requirements definition, interface definition, tradeoff and optimization studies, feasibility studies, risk analysis, and software support studies (18:13).

During this phase the TEMP and the CRLCMP should be updated to reflect the refined requirements (18:13,14). The CRLCMP should address system concepts, system description, computer resource design, organizational responsibilities, resources (to include personnel, facilities, training, hardware, software, and integrated logistics support), management practices, and schedules (18:42-45).

Software prototypes may be developed and demonstrated during this phase (13:64; 18:13). Additionally, plans for software quality evaluation and configuration management should be developed at this time (18:14). A system design review is held and an authenticated system/segment specification should result from this phase (13:64,65; 18:14).

Full-Scale Development

The full-scale development phase is when the system, subsystems, support systems, software, training, and facilities are designed, built, tested and evaluated (13:65; 18:15). This is the first time during the acquisition life cycle when all the subsystems are put together to make a prototype of the end product. With this prototype, tests are done and

preliminary data concerning operations and maintenance can be collected. The tests also show whether or not the subsystems can work together as designed. Additional software requirements may also be identified during this phase (13:65).

Additional software requirements analysis is done, culminating in the completion and authentication of interface requirements specifications and software requirements specifications for each computer software configuration item (13:65). Hardware configuration items, and their associated software are also authenticated during design reviews (13:65).

During the full-scale development phase, reviews are conducted. The software development reviews include the Software Specification Review (SSR), the Preliminary Design Review (PDR), the Critical Design Review (CDR), the Test Readiness Review (TRR), the Functional and Physical Configuration Audits (FCA, PCA), and the Formal Qualification Review (FQR) (18:15). A third party, not belonging to the program office or the contractor, should also do an independent verification and validation of the software for functional effectiveness and technical sufficiency (18:15).

In addition to reviews of the subsystems, the hardware and software configuration items are integrated and tested to validate that the system meets requirements (18:15). The tests are divided into two parts. There is the Development Test and Evaluation (DT&E) where a technical assessment is done to determine whether or not the system meets the specifications (18:15). The Operational Test and Evaluation (OT&E) is done to assess whether or not the system meets the operational requirements (18:15).

The CRWG is responsible for updating the CRLCMP to reflect changes made in life cycle planning activities and the program during this phase (18:15). Other documentation delivered in this phase include a software test plan, a preliminary computer system operator's manual, preliminary user's manuals, a preliminary computer system design manual, a computer resources integrated support document, software test descriptions, a software programmer's manual, and other support manuals (13:65,66,67).

Production and Deployment

Sometimes this phase is broken into two separate phases: the production phase and the deployment phase. In this appendix it is treated as one phase with "two overlapping periods" (13:68). The production periods spans the time from when production is approved to when the last system is delivered by the contractor and accepted by the government (13:68;18:16). The deployment period starts with the delivery and acceptance of the first system, and ends when the last articles of the system are removed from the operational inventory (13:68;18:17).

Software items and hardware items are reproduced for each separate system during this phase (18:16). Any redevelopment or changes in the software during this time will follow the same development life cycle used during the full-scale development phase (13:68;18:16). Software systems operator's manuals and user's manuals should be delivered with the completed systems. Finally, Follow-On Test and Evaluation (FOT&E) is accomplished on the delivered systems to assess their operational effectiveness in their deployed environment (13:68).

Conclusion

Between each of the four phases, the government decides whether or not to continue with the program. These decisions are based on information gathered during the reviews and tests conducted during the previous phase. Coordination between all government agencies and contractor agencies will help to ensure that life cycle costs are kept to a minimum by keeping changes in the design minimal.

Appendix D: Interview Comments

This appendix contains some of the comments considered interesting or significant. These comments were given by persons interviewed and may or may not have been direct answers to the questions contained in the interview guide.

"One of the biggest concerns I have . . . is that software has been ignored for a long, long time. We've got two programs right now in jeopardy. One program has been in slip for two years because of software. Unfortunately, the contractor did not put the emphasis on the software that should have been placed--the documentation became very, very sloppy--and, is now two years late in doing an FCA/PCA, and so we're in a stall mode."

". . . And I need good training on what software documentation is really needed, . . . lifecycle management of software. I really need training on that. . . . Three week courses are too long. You need to break it down to around three day increments, and it could be in several sessions. We need to be able to do it in a way that people could come out of their programs and go to those sort of things."

"I guess we gotta emphasize and face up to 'how do you test software?' We don't know how to do that--really don't know how to do that."

"ASD is more used to dealing with hardware than they are with software, and based on that, software tends to get the short end of the stick."

"Another issue is . . . organic maintenance in terms of the Air Force. It's questionable in my mind whether or not that's reasonable given the intensity of the software, the complexity of the software in our systems."

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VITA

Captain Cynthia L.A. Norman was born on 5 February 1961 at Schilling AFB, Kansas. She graduated from high school in Kealahou, Hawaii, in 1979 and subsequently attended the United States Air Force Academy in Colorado. In June 1983, she received a Bachelor of Science degree after majoring in Computer Science and was commissioned in the United States Air Force. She was then assigned as an information systems programmer and analyst, and Operations Readiness System Project Officer to the Logistics Management Systems Center, Air Force Logistics Command, Wright-Patterson AFB, Ohio, until entering the School of Systems and Logistics, Air Force Institute of Technology, in June 1986.

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REPORT DOCUMENTATION PAGE

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Block 19

ABSTRACT

Research and development of new weapon systems can be very expensive. In addition, the maintenance of these new systems can be expensive, adding to the overall life cycle cost of the systems. Proper design of the new systems can lessen the maintenance costs. However, more and more, weapon systems are not just a product of hardware engineering. Computer systems and software help to run the systems more efficiently and make it easier for humans to control the sophisticated hardware.

The Air Force Systems Command is currently the main procurer of new weapons systems for the Air Force. In particular, the Aeronautical Systems Division (ASD) buys aircraft and aircraft systems for the Air Force. Currently, ASD has a "pool" of engineers for program offices to draw upon whenever hardware technical expertise is needed, but the pool of software experts is very small. Do the majority of the program offices need such a pool of software experts, and if they do, what type of educational and work experience should these people have?

To answer this question, the views of people who are in the program offices were collected. Program managers and software personnel were asked to give their views on education, training, and work experience.

The overwhelming response is that the program offices do need software experts, and that even though they have someone in the office who is the designated software person, the program offices still do not have enough support in the management of software. Additionally, the recommended educational background is in a computer engineering discipline. This education should be enhanced with training in systems acquisition and computer resources acquisition management. If possible, many of the program offices would like their personnel to come to the program with prior program office experience.

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